STATE OF DELAWARE
DEPARTMENT OF TRANSPORTATION
800 BAY ROAD
P.O. BOX 778
DOVER, DELAWARE 19903

CAROLANN WICKS, P.E.
SECRETARY

March 20, 2008

Dear Bridge Design Manual Holder:

SUBJECT: The Delaware Department of Transportation 2005 Bridge Design Manual - January 2008 Revision

This is the formal issuance of the January 2008 Revision to the Delaware Department of Transportation's 2005 Bridge Design Manual. This revision will be effective March 31, 2008. You can download this revision from DelDOT's web site, http://www.deldot.gov/information/pubs_forms/manuals/bridge_design/index.shtml. Changes have been made to Sections 3.4 and 3.4.1.1 regarding scour evaluation and protection.

Please replace the pages in your manual with the appropriate sheets. If you should have any questions, please contact Linda Osiecki at (302) 760-2342.

Sincerely yours,

Dennis M. O'Shea

Dennis M. O'Shea
Assistant Director - Design

DMO:los
cc: Robert Taylor, Chief Engineer
Kevin T. Canning, Quality Engineer
Linda M. Osiecki, Program Manager, Quality
Jiten Soneji, Bridge Design Engineer
George Spadafino, Quality Review Engineer
Keith Gray, FHWA

DelDOT

3.4 SCOUR EVALUATION AND PROTECTION

Changes in the bed level of a stream affect highway structures and may be described by three types of actions: (1) general scour (contraction scour), (2) local scour, and (3) degradation or aggradation of the stream channel. Scour and degradation are discussed in this section. Other types of erosion and aggradation are discussed in Section 3.5.

Every bridge over a waterway should be evaluated as to its vulnerability to scour in order to determine the appropriate protective measures. Most waterways can be expected to experience scour over a bridge's service life (which could approach 100 years). The need to ensure public safety and to minimize the adverse effects stemming from bridge closures requires the best effort to improve the state-of-practice of designing and maintaining bridge foundations to resist the effects of scour. Current information on this subject has been assembled in *HEC-18, Evaluating Scour at Bridges*.

Scour evaluations of new and existing bridges should be conducted by an interdisciplinary team composed of hydraulic, geotechnical, and structural engineers.

Bridges over waterways—both tidal and non-tidal—with scourable beds should withstand the effects of scour from a superflood (500-year flood) without failing.

Hydraulic studies shall include estimates of scour at bridge piers and evaluation of abutment stability. Bridge foundations shall be designed to withstand the effects of scour for the worst conditions resulting from floods. The geotechnical analysis of bridge foundations shall be performed on the basis that all streambed material in the scour prism above the total scour line for the designated flood (for scour) has been removed.

For the design flood, the stability of the bridge foundation shall be investigated using the service and strength limit states. The design flood for scour shall be the more severe of the 100-year event or from an overtopping event of smaller recurrence interval.

For the Q_{500} super flood conditions, the foundation shall be designed to be stable for the extreme event limit state. The super flood for scour shall be the more severe of the 500-year event or from an overtopping event of smaller recurrence interval.

In general, foundations shall be designed to be stable without relying on scour countermeasures. The only exception to this is when designing for local scour at abutments. Because the local scour equations tend to overestimate the magnitude of scour at abutments, they are generally used only to gain insight into the scour potential at an abutment. In most cases, a scour countermeasure, properly designed and installed in accordance with the procedures outlined in HEC-23, is provided to resist the local scour at abutments. Both the abutment foundation and the scour countermeasure must be designed to be stable after the effects of the estimated long-term degradation and contraction scour. Ensure that the top of the footing is below the sum of the long-term degradation, contraction scour, and lateral migration; stub abutments are an exception to this requirement, but the slopes in front of them should be adequately protected and/or sheeting should be provided to prevent undermining of the abutment and loss of fill. Riprap (minimum size R-5) must always be used to protect abutments from erosion for maintenance purposes, even if it is not required to resist the effects of local scour.

The *AASHTO Specifications* contain requirements for designing bridges to resist scour. Particular attention is directed to Sections 2.6.4.4.2 and 3.7.5.

3.4.1 EVALUATION CRITERIA

3.4.1.1 Analysis Procedure

Scour analysis should be performed according to the FHWA publication *HEC-18, Evaluating Scour at Bridges*. Computer software HY-9, Scour at Bridges, should be used to check the manual calculations. Any countermeasures required should be designed using the methods in:

- *HEC-18, Evaluating Scour at Bridges*,
- *HEC-11, Design of Riprap Revetment*,
- *FHWA-HI-90-016, Highways in the River Environment*,
- *HEC-20, Stream Stability at Highway Structures*, or
- *HEC-23, Bridge Scour and Stream Instability Countermeasures*.

Minimum riprap size must conform with the requirements of R-5 in Section 712 of the Standard Specifications. Larger riprap may be specified if it is needed. The riprap in the channel shall be covered with a minimum of one foot of natural stream bed channel. A low-flow channel shall be formed at that point, if applicable.

Also refer to *NCHRP Report 587, Countermeasures to Protect Bridge Abutments from Scour*.

3.4.1.2 Scourability of Rock

Evaluate the scour potential of rock by following the procedure for rock quality designation (RQD) in FHWA Mid-Atlantic Region Memorandum, Scourability of Rock Formations, to determine scourability. The following criteria represent the values to define rock quality and scourability of rock:

- The RQD value is a modified computation of the percent of rock core recovery that reflects the relative frequency of discontinuities and the compressibility of the rock mass and may indirectly be used as a measure of scourability. The RQD is determined by measuring and summing all the pieces of sound rock 6 inches [150 mm] and longer in a core run and dividing this by the total core run length. The RQD should be computed using NX diameter cores or larger and on samples from double tube core barrels. Scourability potential will increase as the quality of rock becomes poorer. Rock with an RQD value of less than 50 percent should be assumed to be soil-like with regard to scour potential.
- The primary intact rock property for foundation design is unconfined compressive strength (ASTM Test D2938). Although the strength of jointed rocks is generally less than individual units of the rock mass, the unconfined compressive strength provides an upper limit of the rock mass bearing capacity and an index value for rock classification. In general, samples with unconfined compressive strength below 250 psi [1724 kPa] are not considered to behave as rock. There is only a generalized correlation between unconfined compressive strength and scourability.
- The slake durability index (SDI as defined by the International Society of Rock Mechanics) is a test used on metamorphic and sedimentary rocks such as slate and shale. An SDI value of less than 90 indicates poor rock quality. The lower the value, the more scourable and less durable the rock.

- AASHTO Test T104 is a laboratory test for soundness of rock. A soaking procedure in magnesium and sodium sulfate solution is used. Generally the less sound the rock, the more scourable it will be. Threshold loss rates of 12 (sodium) and 18 (magnesium) can be used as an indirect measure of scour potential.
- The Los Angeles abrasion test (AASHTO T96) is an empirical test to assess abrasion of aggregates. In general, the less a material abrades during this test, the less it will scour. Loss percentages greater than 40 percent indicate scourable rock.

The other methods described in that memorandum should be used if required. For other soil types, existing surface borings and tests of soil samples should be interpreted.

3.4.1.3 Scour Evaluation Report

The scour evaluation report must contain the following items:

- table of contents;
- bridge description—bridge number, type, size, location, and National Bridge Inventory Record Item 113, Scour coding;
- executive summary of hydrologic and hydraulic methods, scour results, conclusions, and any countermeasure recommendations required, with plan and profile views showing scour depths and limits;
- scour computations (including computer input and output);
- bridge drawings, cross sections, soils information, test results, and other miscellaneous data; and
- references.

3.4.1.4 Plan Presentation

The following information will be provided in the Project Notes on the plans:

- a note stating that the structure has been analyzed for the effects of scour in accordance with the procedures described in *HEC-18, Evaluating Scour at Bridges*;
- scour analysis design flow volume, frequency, velocity, and water surface elevation;
- scour analysis check flow volume, frequency, velocity, and water surface evaluation;
- the calculated design scour depth; and
- the calculated check scour depth.

See Figure 3-6 for a sample scour project note.

Figure 3-6
Sample Scour Project Note

THE PROPOSED STRUCTURE HAS BEEN ANALYZED FOR THE EFFECTS OF SCOUR IN ACCORDANCE WITH HEC-18 - 'EVALUATING SCOUR AT BRIDGES' AND HEC-23 - 'BRIDGE SCOUR AND STREAM INSTABILITY COUNTERMEASURES.' SCOUR COUNTERMEASURES HAVE BEEN DESIGNED FOR THE WORST CASE OF THE OVERTOPPING FLOOD OR THE 500-YR FLOOD EVENT.

DESIGN EVENT	OVERTOPPING	DESIGN VELOCITY	6.22 FT/S
DESIGN DISCHARGE	535 CFS	DESIGN DEPTH OF FLOW	6.14 FT

3.5 STREAM STABILITY

3.5.1 STREAM STABILITY ANALYSIS

Erosion is considered to be the loss of material on side slopes and stream banks. Types of stream erosion include:

- scour (see Section 3.4);
- the natural tendency of streams to meander within the flood plain;
- bank erosion; and
- degradation.

These are all interrelated to some degree.

The computed velocity is a measure of the potential erosion and scour. Exit velocity from culverts will be computed on the assumptions shown in *HDS-5, Hydraulic Design of Highway Culverts*. (Use HY-8, Culvert Analysis, software based on HDS-5 for the computations.) Average velocity computed on the gross waterway will be the representative velocity for open span structures, furnished by computer analysis for water surface elevations.

Examples of highly erodible soil can be found in all areas of the state. Areas of loamy deposits, which are highly sensitive to erosion, are prevalent in Delaware. County SCS soil maps may aid in judging the in-situ material.

The designer must consider the downstream erosion potential in evaluating and sizing the structure. Under some conditions, any additional erosion would be intolerable. Thus, risk considerations should be included in the site study. It should be recognized that stream banks erode regardless of the presence of a highway crossing. Any alteration of erosion potential by a structure must be closely evaluated in judging the adequacy of a design.

Streams naturally tend to seek their own gradient through either degradation or aggradation. Degradation is the erosion of streambed material, which lowers the streambed. Aggradation is the transport and deposition of the eroded material to change the streambed at another location. The effect of the structure on degradation or aggradation of a stream must be evaluated in bridge crossing design.

The designer should evaluate the stability of the bed and banks of the waterway channel, including lateral movement, aggradation, and degradation, using *HEC-20, Stream Stability at Highway Structures*.

3.5.2 BANK PROTECTION

The most common method of bank protection is the use of rock riprap. Factors to consider in the design of rock riprap protection include:

- the stream velocity,
- the angle of the side slopes, and
- the size of the rock.

Filter blankets of smaller gradation bedding stone or geotextiles are used under riprap to stabilize the subsoil and prevent piping damage. Riprap bank protection should terminate with a flexible cut-off wall.

The designer should specify a minimum blanket thickness of 18 inches [460 mm] for embankment protection and 24 inches [610 mm] for slope protection along stream banks and for streambeds. Refer to *FHWA-HI-90-016, Highways in River Environment*, and *HEC-11, Design of Riprap Revetment*. See Figure 3-7 for typical riprap details and an example of a riprap installation.

3.4 SCOUR EVALUATION AND PROTECTION

Changes in the bed level of a stream affect highway structures and may be described by three types of actions: (1) general scour (contraction scour), (2) local scour, and (3) degradation or aggradation of the stream channel. Scour and degradation are discussed in this section. Other types of erosion and aggradation are discussed in Section 3.5.

Every bridge over a waterway should be evaluated as to its vulnerability to scour in order to determine the appropriate protective measures. Most waterways can be expected to experience scour over a bridge's service life (which could approach 100 years). The need to ensure public safety and to minimize the adverse effects stemming from bridge closures requires the best effort to improve the state-of-practice of designing and maintaining bridge foundations to resist the effects of scour. Current information on this subject has been assembled in *HEC-18*, *Evaluating Scour at Bridges*.

Scour evaluations of new and existing bridges should be conducted by an interdisciplinary team composed of hydraulic, geotechnical, and structural engineers.

Bridges over waterways—both tidal and non-tidal—with scourable beds should withstand the effects of scour from a superflood (500-year flood) without failing.

Hydraulic studies shall include estimates of scour at bridge piers and evaluation of abutment stability. Bridge foundations shall be designed to withstand the effects of scour for the worst conditions resulting from floods. The geotechnical analysis of bridge foundations shall be performed on the basis that all streambed material in the scour prism above the total scour line for the designated flood (for scour) has been removed.

For the design flood, the stability of the bridge foundation shall be investigated using the service and strength limit states. The design flood for scour shall be the more severe of the 100-year event or from an overtopping event of smaller recurrence interval.

For the Q_{500} super flood conditions, the foundation shall be designed to be stable for the extreme event limit state. The super flood for scour shall be the more severe of the 500-year event or from an overtopping event of smaller recurrence interval.

In general, foundations shall be designed to be stable without relying on scour countermeasures. The only exception to this is when designing for local scour at abutments. Because the local scour equations tend to overestimate the magnitude of scour at abutments, they are generally used only to gain insight into the scour potential at an abutment. In most cases, a scour countermeasure, properly designed and installed in accordance with the procedures outlined in HEC-23, is provided to resist the local scour at abutments. Both the abutment foundation and the scour countermeasure must be designed to be stable after the effects of the estimated long-term degradation and contraction scour. Ensure that the top of the footing is below the sum of the long-term degradation, contraction scour, and lateral migration; stub abutments are an exception to this requirement, but the slopes in front of them should be adequately protected and/or sheeting should be provided to prevent undermining of the abutment and loss of fill. Riprap (minimum size R-5) must always be used to protect abutments from erosion for maintenance purposes, even if it is not required to resist the effects of local scour.

The *AASHTO Specifications* contain requirements for designing bridges to resist scour. Particular attention is directed to Sections 2.6.4.4.2 and 3.7.5.

3.4.1 EVALUATION CRITERIA

3.4.1.1 Analysis Procedure

Scour analysis should be performed according to the FHWA publication *HEC-18, Evaluating Scour at Bridges*. Computer software HY-9, Scour at Bridges, should be used to check the manual calculations. Any countermeasures required should be designed using the methods in:

- *HEC-18, Evaluating Scour at Bridges*,
- *HEC-11, Design of Riprap Revetment*,
- *FHWA-HI-90-016, Highways in the River Environment*,
- *HEC-20, Stream Stability at Highway Structures*, or
- *HEC-23, Bridge Scour and Stream Instability Countermeasures*.

Minimum riprap size must conform with the requirements of R-5 in Section 712 of the Standard Specifications. Larger riprap may be specified if it is needed. The riprap in the channel shall be covered with a minimum of one foot of natural stream bed channel. A low-flow channel shall be formed at that point, if applicable.

Also refer to *NCHRP Report 587, Countermeasures to Protect Bridge Abutments from Scour*.

3.4.1.2 Scourability of Rock

Evaluate the scour potential of rock by following the procedure for rock quality designation (RQD) in FHWA Mid-Atlantic Region Memorandum, Scourability of Rock Formations, to determine scourability. The following criteria represent the values to define rock quality and scourability of rock:

- The RQD value is a modified computation of the percent of rock core recovery that reflects the relative frequency of discontinuities and the compressibility of the rock mass and may indirectly be used as a measure of scourability. The RQD is determined by measuring and summing all the pieces of sound rock 6 inches [150 mm] and longer in a core run and dividing this by the total core run length. The RQD should be computed using NX diameter cores or larger and on samples from double tube core barrels. Scourability potential will increase as the quality of rock becomes poorer. Rock with an RQD value of less than 50 percent should be assumed to be soil-like with regard to scour potential.
- The primary intact rock property for foundation design is unconfined compressive strength (ASTM Test D2938). Although the strength of jointed rocks is generally less than individual units of the rock mass, the unconfined compressive strength provides an upper limit of the rock mass bearing capacity and an index value for rock classification. In general, samples with unconfined compressive strength below 250 psi [1724 kPa] are not considered to behave as rock. There is only a generalized correlation between unconfined compressive strength and scourability.
- The slake durability index (SDI as defined by the International Society of Rock Mechanics) is a test used on metamorphic and sedimentary rocks such as slate and shale. An SDI value of less than 90 indicates poor rock quality. The lower the value, the more scourable and less durable the rock.

STATE OF DELAWARE
DEPARTMENT OF TRANSPORTATION
800 BAY ROAD
P.O. BOX 778
DOVER, DELAWARE 19903

CAROLANN WICKS, P.E.
SECRETARY

May 6, 2008

Dear Bridge Design Manual Holder:

SUBJECT: The Delaware Department of Transportation 2005 Bridge Design Manual - April 2008 Revision

This is the formal issuance of the April 2008 revision to the Delaware Department of Transportation's 2005 Bridge Design Manual. This revision will be effective May 12, 2008. You can download this revision from DelDOT's web site, http://www.deldot.gov/information/pubs_ forms/manuals/bridge_design/index.shtml. Section 8.1.3 regarding covered bridge painting has been added.

Please replace the pages of your manual with the appropriate sheets. If you should have any questions, please contact Linda Osiecki at (302) 760-2342.

Sincerely yours,

Dennis O'Shea
Assistant Director – Design

DMO:los
cc: Robert Taylor, Chief Engineer
Linda M, Osiecki, Program Manager, Quality
Jiten Soneji, Bridge Design Engineer
George Spadafino, Quality Review Engineer
Keith Gray, FHWA

DelDOT

Chapter Eight

Timber Structures Design

8.1 INTRODUCTION

As of 2005, almost three percent of Delaware's bridges were timber.

DelDOT's construction of timber bridges has decreased in proportion to its use of other materials over the last 50 years. This is due to an increasing use of steel and concrete to accommodate longer spans, increased traffic and larger truck loads. Today, most new timber bridges constructed by DelDOT are single spans over tax ditches and creeks on low-volume roads.

Other uses of timber by DelDOT include piles, barriers, railings, boardwalks, decks, fender systems, privacy fences, landscaping, railroad ties, and retaining walls.

This chapter will discuss general aspects of timber bridges, physical and mechanical properties of timber, preservatives, hardware, design criteria, and the design of various components of bridges using wood. These topics will be discussed in enough detail to give designers the insight needed to design timber bridges that are constructable, functional, durable, and maintainable. Emphasis will be placed on the types of timber bridges in use on the state's highway system. Where appropriate, the designer is referred to other references for details not presented here.

8.1.1 ADVANTAGES AND DISADVANTAGES OF TIMBER BRIDGES

The main advantages of timber bridges relative to other bridge materials are:

- Ease of construction;
- Ease of maintenance;
- Pleasing appearance;
- Renewable resource;
- Consstruction is not weather-dependent;
- Lightweight.

The main disadvantages of timber bridges are:

- Susceptibility to vandalism.
- Rapid decay in the absence of proper treatment.
- The need to account for irregularities in the material in design and construction.
- Frequent maintenance requirements.

8.1.2 TIMBER AS A BRIDGE MATERIAL

Timber can be used to construct many different types of bridge systems. In Delaware, some of them are:

- Beam
- Deck
- Truss

Most timber bridges currently being built in the state are laminated deck type systems. However, many beam type systems constructed prior to the 1960's are still in DelDOT's bridge inventory.

Many different qualities and species of wood are available for construction. Because of the large variation in timber qualities, the bridge designer must carefully specify wood materials. This is to insure that the timber specified is available, durable, and can safely carry the design loads and satisfy serviceability limit states.

Construction of timber beam and deck bridge systems in Delaware is carried out using various types of lumber. Variations in lumber used in bridge construction include:

- Species of the tree;
- Physical properties of the lumber;
- Mechanical properties of the lumber;
- Sawn or laminated lumber;
- Preservative treatments.

Additional design considerations are:

- Superstructure type;
- Types of fasteners;
- Railings;
- Wearing surfaces;
- Fire resistance and/or protection;
- Substructure type.

8.1.2.1 TIMBER BEAM SUPERSTRUCTURE

Beam type systems are the simplest type of timber bridge. Most consist of a series of longitudinal beams supported by piers and abutments. Typically spans can range from 10 to 30 ft [3 to 9 m] depending on the beam type. Most of the bridges of this type on Delaware's highway system were built prior to the 1960's. Timber beam systems include:

- Sawn Lumber Beams
- Glue Laminated Beams

Most timber beam type bridges in Delaware are sawn lumber beams, and most range in span from 10 to 20 ft [3 to 6 m]. The beams are typically less than 3 feet [1 m] apart, and are commonly 4 to 8 in [100 to 200 mm] wide and 12 to 18 in [300 to 450 mm] deep. Decks on beam superstructures are typically constructed of 2 to 4 in [50 to 100 mm] thick planks placed transverse to the beams. The planks are typically not overlaid with a wearing surface, because they deflect under load, causing cracking of the wearing surface.

8.1.2.2 LONGITUDINAL DECK SUPERSTRUCTURES

Longitudinal deck superstructures are the primary types of timber bridges currently being constructed in Delaware. Longitudinal deck superstructures are constructed by glue laminating timber planks together to form panels, and then, if possible, stress laminating the panels together to form a rigid deck unit. The deck is typically overlaid with hot-mix. See Section 8.7 for more design details.

Longitudinal deck superstructures are typically between 8 and 16 in [200 and 400 mm] deep. They can be used economically and practically for clear spans up to approximately 30 ft [9 m]. The low profile of these bridges makes them desirable when vertical clearance below the bridge is limited.

8.1.3 COVERED BRIDGE PAINTING

Uniform paint colors shall be used for all covered bridges in Delaware as follows:

- Primary Color for Siding/Exterior - Red Federal Standard 595 Color 20152
- Secondary Color for Trim - White Federal Standard 595 Color 37925

The paint shall be a flat finish (low luster). The plans shall note which of these colors shall be used in other locations.

8.2 PHYSICAL PROPERTIES OF STRUCTURAL TIMBER

Physical properties of wood refer to its natural qualities. Numerous factors have an effect on the physical properties of wood. Designers must be aware of these factors and specify allowable mechanical properties for use in design. Mechanical properties of lumber are discussed in Section 8.3. Factors having an effect on the physical properties of wood are:

- Species
- Direction of grain
- Moisture content
- Density
- Knots
- Durability

8.2.1 LUMBER SPECIES

Lumber is manufactured from a great variety of timber species. Physical properties of each species vary. Some species of timber are strong and durable, while others are not. Species with similar mechanical properties are classified into groups. Typically, several species suitable for bridge construction are available in a given location. In Delaware, the preferred species for use in bridge construction are Douglas fir and southern yellow pine. For the replacement of historic covered bridges, the exotic fire-resistant wood bongossi/azobe (Lophira alata) may be used with the approval of the Bridge Design Engineer.

8.2.2 DIRECTION OF GRAIN

Wood grows as fibers that run in the direction of the tree trunk. Parallel to the wood fibers is “with the grain”. Perpendicular to the direction of the fibers is “against the grain”. Wood has different structural properties in each of these directions, which must be accounted for in design.

8.2.3 MOISTURE CONTENT

Moisture content of wood is the weight of water it contains divided by its dry weight. Moisture content is typically expressed as a percentage. Moisture content of timber varies by species and structural application. Wood is a hygroscopic material, which means that it absorbs moisture in humid environments and loses moisture in dry environments. As the moisture content of wood changes, so does its strength. Wood with lower moisture content has higher strength. The factors used to make strength adjustments based on changes in the physical condition of wood are given in Section 8.3.4.2. Moisture content of wood used in timber bridges is a function of use above or below the water line, temperature, and humidity.

As the moisture content of wood changes, wood shrinks and swells. With the grain, average shrinkage values for green to oven dry conditions range between 0.1 and 0.2 percent; this is generally of no concern to the designer. Against the grain, shrinkage is much more pronounced. The effect of uneven drying in two different directions perpendicular to the grain can cause wood to warp. This commonly occurs in thin planks. Typically, bridge designers do not have to make shrinkage calculations; however, they should understand how shrinkage occurs and guard against its detrimental effects.

8.2.4 DENSITY

Density of wood varies with species and moisture content. Density for most species varies between 20 and 50 pcf [320 and 800 kg/m^3]. For most bridge applications, density is taken as 50 pcf [800 kg/m^3]. The density of bongossi is 66 pcf to 75 pcf [1060 to 1205 kg/m^3]. Density of wood and strength are closely related. Generally, as density increases, strength increases proportionally. Density is also important in buoyancy calculations.

8.2.5 KNOTS

Knots are formed by a branch that has been surrounded by growth of the trunk. Knots reduce the strength of wood because they interrupt the continuity and direction of wood fibers.

8.2.6 DURABILITY

The natural durability of wood is defined as its resistance to decay and insect attack. Natural durability of wood varies with species. In general, only the heartwood of a tree is considered naturally durable. Heartwood is the interior of the tree trunk which is composed of inactive wood cells. Because of variations in durability, it is unreliable for the bridge designer to depend on natural wood durability in structural applications. Therefore, the wood used in structural applications is treated to resist decay and attack from insects. Preservative treatments for wood will be further discussed in Section 8.4.

8.3 MECHANICAL PROPERTIES

Mechanical properties describe the characteristics of a material in response to externally applied forces. Designers are mainly concerned with elastic and strength properties.

Elastic properties relate a material's resistance to deformation under an applied load and ability of the material to regain its original dimensions when the load is removed. There are three elastic properties of wood: modulus of elasticity, shear modulus, and Poisson's ratio. Each of these elastic properties has different values depending on species, grade, and orientation of the applied load to the direction of the grain. The only elastic property of wood that is typically required in bridge design is modulus of elasticity in the longitudinal direction. This value relates the stress occurring in that direction to the strain occurring along the same axis.

Strength properties describe the ultimate resistance of a material to applied loads. They include compression, tension, shear, bending, and torsion. As with elastic properties, strength properties of wood vary in different directions along the grain and with species and grade.

Mechanical properties of wood vary greatly. Even timber members cut from the same log can have widely varying mechanical properties. The mechanical properties of any given member are a direct result of its inherent physical properties. This leads to a fairly elaborate system for both lumber grading at the mill and determination of mechanical properties to be used in design. Wood strength and elastic design values are found in the *AASHTO Specifications*, Section 8.4.

8.3.1 SAWN LUMBER GRADING

Mechanical properties of sawn lumber are a function of species, physical condition of the member, size, and structural application.

Most timber bridges currently being built in the state are laminated deck type systems. However, many beam type systems constructed prior to the 1960's are still in DelDOT's bridge inventory.

Many different qualities and species of wood are available for construction. Because of the large variation in timber qualities, the bridge designer must carefully specify wood materials. This is to insure that the timber specified is available, durable, and can safely carry the design loads and satisfy serviceability limit states.

Construction of timber beam and deck bridge systems in Delaware is carried out using various types of lumber. Variations in lumber used in bridge construction include:

- Species of the tree;
- Physical properties of the lumber;
- Mechanical properties of the lumber;
- Sawn or laminated lumber;
- Preservative treatments.

Additional design considerations are:

- Superstructure type;
- Types of fasteners;
- Railings;
- Wearing surfaces;
- Fire resistance and/or protection;
- Substructure type.

8.1.2.1 TIMBER BEAM SUPERSTRUCTURE

Beam type systems are the simplest type of timber bridge. Most consist of a series of longitudinal beams supported by piers and abutments. Typically spans can range from 10 to 30 ft [3 to 9 m] depending on the beam type. Most of the bridges of this type on Delaware's highway system were built prior to the 1960's. Timber beam systems include:

- Sawn Lumber Beams
- Glue Laminated Beams

Most timber beam type bridges in Delaware are sawn lumber beams, and most range in span from 10 to 20 ft [3 to 6 m]. The beams are typically less than 3 feet [1 m] apart, and are commonly 4 to 8 in [100 to 200 mm] wide and 12 to 18 in [300 to 450 mm] deep. Decks on beam superstructures are typically constructed of 2 to 4 in [50 to 100 mm] thick planks placed transverse to the beams. The planks are typically not overlaid with a wearing surface, because they deflect under load, causing cracking of the wearing surface.

8.1.2.2 LONGITUDINAL DECK SUPERSTRUCTURES

Longitudinal deck superstructures are the primary types of timber bridges currently being constructed in Delaware. Longitudinal deck superstructures are constructed by glue laminating timber planks together to form panels, and then, if possible, stress laminating the panels together to form a rigid deck unit. The deck is typically overlaid with hot-mix. See Section 8.7 for more design details.

Longitudinal deck superstructures are typically between 8 and 16 in [200 and 400 mm] deep. They can be used economically and practically for clear spans up to approximately 30 ft [9 m]. The low profile of these bridges makes them desirable when vertical clearance below the bridge is limited.

8.1.3 COVERED BRIDGE PAINTING

Uniform paint colors shall be used for all covered bridges in Delaware as follows:

- Primary Color for Siding/Exterior - Red Federal Standard 595 Color 20152
- Secondary Color for Trim - White Federal Standard 595 Color 37925

The paint shall be a flat finish (low luster). The plans shall note which of these colors shall be used in other locations.

8.2 PHYSICAL PROPERTIES OF STRUCTURAL TIMBER

Physical properties of wood refer to its natural qualities. Numerous factors have an effect on the physical properties of wood. Designers must be aware of these factors and specify allowable mechanical properties for use in design. Mechanical properties of lumber are discussed in Section 8.3. Factors having an effect on the physical properties of wood are:

- Species
- Direction of grain
- Moisture content
- Density
- Knots
- Durability

8.2.1 LUMBER SPECIES

Lumber is manufactured from a great variety of timber species. Physical properties of each species vary. Some species of timber are strong and durable, while others are not. Species with similar mechanical properties are classified into groups. Typically, several species suitable for bridge construction are available in a given location. In Delaware, the preferred species for use in bridge construction are Douglas fir and southern yellow pine. For the replacement of historic covered bridges, the exotic fire-resistant wood bongossi/azobe (Lophira alata) may be used with the approval of the Bridge Design Engineer.

8.2.2 DIRECTION OF GRAIN

Wood grows as fibers that run in the direction of the tree trunk. Parallel to the wood fibers is “with the grain”. Perpendicular to the direction of the fibers is “against the grain”. Wood has different structural properties in each of these directions, which must be accounted for in design.

8.2.3 MOISTURE CONTENT

Moisture content of wood is the weight of water it contains divided by its dry weight. Moisture content is typically expressed as a percentage. Moisture content of timber varies by species and structural application. Wood is a hygroscopic material, which means that it absorbs moisture in humid environments and loses moisture in dry environments. As the moisture content of wood changes, so does its strength. Wood with lower moisture content has higher strength. The factors used to make strength adjustments based on changes in the physical condition of wood are given in Section 8.3.4.2. Moisture content of wood used in timber bridges is a function of use above or below the water line, temperature, and humidity.

As the moisture content of wood changes, wood shrinks and swells. With the grain, average shrinkage values for green to oven dry conditions range between 0.1 and 0.2 percent; this is generally of no concern to the designer. Against the grain, shrinkage is much more pronounced. The effect of uneven drying in two different directions perpendicular to the grain can cause wood to warp. This commonly occurs in thin planks. Typically, bridge designers do not have to make shrinkage calculations; however, they should understand how